

SHORT-TERM MEMORY IN THE PIGEON: STIMULUS-RESPONSE ASSOCIATIONS¹

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Three pigeons pecked for food in two experiments in which each trial consisted of two phases: a study and a test phase. The study phase in Experiment I consisted of two stimulus-response pairs presented successively. Each pair consisted of the illumination of a left or right key (the stimulus) and a peck on the lighted side key (the response). The study phase in Experiment II consisted of three such pairs presented successively. A retention interval, varied between 0.1 and 4.0 sec, separated the study phase from the test phase. The test phase of a trial began with the illumination of the center key by one of two (Experiment I) or three (Experiment II) colors. This color was the same as the stimulus element of one of the pairs in the study phase. A reinforcer was presented if a subject then emitted the response element of the indicated stimulus-response pair. The results provide information on the conditions that enable a pigeon to remember the responses most recently emitted in the presence of various stimuli. The results suggest an account of the maintenance of behavior that is temporally noncontiguous with reinforcement.

It is commonly agreed that concepts derived from the study of human memory have in recent years revolutionized the study of human learning and conditioning (Estes, 1973; Melton and Martin, 1972; Tulving and Madigan, 1970). A corresponding revolution is conspicuously absent from the study of animal learning and conditioning.

One feature common to nearly all recent theoretical treatments of human learning is the assumption that memory for recent events can form part of the functional stimulus (Estes, 1973; Tulving and Madigan, 1970). In this regard, recent theories for human learning contrast sharply with recent theories of operant behavior in animals (Herrnstein, 1970; Rachlin, 1973; Catania, 1973). These latter theories disregard any potential implications of short-term memory. Perhaps the study of animal learning could profit, as the study of human learning did, by an experi-

mental examination of the role played by short-term memory.

The potential importance of short-term memory for the construction of a satisfactory theory of animal behavior motivated the present experiment, the purpose of which was to develop a method to study short-term memory for stimulus-response associations in the pigeon. The method developed here can be conveniently introduced as an analog of the following hypothetical experiment on short-term memory in a human subject. A subject is presented with a sequence of trials, each consisting of a "study" phase and a "test" phase. In the study phase, a subject is presented with a short "list" of stimulus-response pairs or "items", presented successively. Each pair in the list consists of a stimulus presented along with the corresponding response, which the subject is required to emit. After exposure to the list of items, a subject waits through a short "retention interval". Then, in the test phase of the trial, the subject is asked to emit the response element of the i^{th} item in the study phase list. The position of the tested item in the list varies from trial to trial, so that the subject must remember which response was associated with which stimulus during the study phase.

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EXPERIMENT I

METHOD

Subjects

Three experimentally naive White Carneaux pigeons were maintained at approximately 80% of their free-feeding weights.

Apparatus

Three standard three-key Lehigh Valley Electronics pigeon chambers were interfaced to a Digital Equipment Corporation PDP-12 computer that arranged all experimental contingencies and recorded the data.

Procedure

Each session consisted of a number of discrete trials and each trial consisted of two phases: a study phase and a test phase.

Study phase. The study phase consisted of the presentation of a list of stimulus-response pairs. At the beginning of a trial, a red light appeared on a randomly selected side key. The first response on that key, after 0.5 sec elapsed from the onset of the stimulus, turned the red light off and began a 0.1-sec interstimulus interval (ISI). This sequence of events constituted the first stimulus-response pair, or item, in the list. During the ISI, all three keys were dark but a houselight remained on. When the ISI timed out, a blue light appeared on a randomly selected side key and the first response to that key, after 0.5 sec elapsed, turned off the blue light. These events formed the second stimulus-response pair. The response element of the second stimulus-response pair began a retention interval, during which the experimental chamber was darkened. Responses on any of the three keys during the

retention interval or the ISI had no scheduled consequences. The duration of the retention interval was varied over experimental conditions as shown in Table 1.

Test phase. The houselight was turned on and a "retrieval cue" was presented on the center key when the retention interval timed out. There were two, equiprobable cues, a red light and a blue light. The first peck on the lighted center key turned off the center key and presented lights of the same color on both side keys. If the center key had been red, the side keys were red. If the center key had been blue, the side keys were blue. One of the side keys was "correct", *i.e.*, a peck on this key was followed by reinforcement. A red center key followed by red side keys meant "remember the first (red) stimulus-response pair presented in the study phase sequence for this trial, and now emit the response element of that pair". A blue retrieval cue meant, "remember the second (blue) stimulus-response pair in the study phase sequence for this trial, and now peck that side key". The houselight remained on throughout the test phase.

If the subject chose the correct side key, the food hopper was presented, the trial ended, and a 1.0-sec intertrial interval began. All lights in the chamber were off during the intertrial interval. Only a light above the food hopper was on during reinforcement.

Correction procedure. An error, defined as a choice of the incorrect side key, was followed by a 2.0-sec "timeout". During the timeout, the houselight remained on and the keylights were off. When the 2.0-sec timeout elapsed, the previous trial on which the error was made was repeated, *i.e.*, the stimuli presented during the study phase and the test phase of the trial were the same as in the previous trial. The correction procedure was repeated until a correct side-key response was made. This correct response was followed by presentation of the food-hopper.

The correction procedure, together with the equal likelihoods of the various stimulus-response pairs and of the retrieval cues, ensured that responses on the two side keys were equally reinforced, thereby minimizing the possibility of the development of a position bias.

Other arrangements. Reinforcement for a correct response was either a 2.0-sec or a 0.25-

Table 1
Experimental Conditions

Condition Number	Number of Items (Stimulus-Response Pairs) in the Study Phase List	Retention Interval (sec)	Number of Days of Training
1	2	2.0	32
2	2	1.0	9
3	2	4.0	20
4	3	0.5	33
5	3	0.1	15
6	3	2.0	17
7	3	4.0	32

sec presentation of mixed grain. The probability of the short food-hopper time on a trial was 0.60. The 0.25-sec presentation, which was too short to enable a pigeon to eat, permitted more trials per session without a confounding satiation effect. The shorter food-hopper duration presumably served as a conditioned reinforcer. No performance decrement was observed as the probability of the shorter duration was increased in pretraining (see below). Sessions lasted 35 min, during which the food hopper was presented 200 to 300 times (counting both shorter and longer reinforcement durations).

Example of a trial in condition 1. Suppose that a trial began with the presentation of a red light on the left key. The subject was required to peck this key before the next stimulus could be presented. Suppose further that the next stimulus was a blue light on the right key. The subject then had to peck this key. A retention interval of 2.0 sec began when the second stimulus-response pair was completed. Let us suppose that a red light was presented on the center key at the end of the retention interval. Red meant "remember the first (red) stimulus-response pair in the study phase". So, on this particular trial the subject was required to peck the center key to present the red side keys and then peck the left key.

Pretraining. The pigeons first were trained to eat from the food hopper and to peck the three keys in the pigeon chamber. On the initial pretraining sessions, the list of stimulus-response pairs for a trial was either left-right or right-left. That is, if the first stimulus in the study phase of the trial was a lighted left-side key, the second stimulus was always a lighted right-side key, and *vice versa*. Both lists were equally probable. In addition, at the beginning of training the pigeon was given temporal cues as follows. If the retrieval cue was to be a red light, *i.e.*, if the subject was to remember the first stimulus-response pair, the computer presented the stimulus component of that pair for 5 sec and the stimulus component of the pair not tested (that is, the second stimulus) for only 0.1 sec. Thus, the second pair produced less retroactive interference than if it had been presented for a longer time (Moffitt, 1972; Zentall, 1973). If a blue light was to be the retrieval cue, *i.e.*, if the subject was to remember the second stimulus-response pair, the computer presented the

stimulus component of that pair for 5 sec and the stimulus component of the first pair for 0.1 sec. In short, the stimulus component of the stimulus-response pair to be remembered on the test phase of the trial was presented for a longer time than the stimulus component of the stimulus-response pair not tested. This technique increased exposure to the relevant item and provided an additional stimulus dimension (duration of the relevant stimulus) to which a subject could attend to "solve" the task. After 32 sessions, the temporal cues were gradually equalized until each stimulus in the sequence was presented for at least 0.5 sec as described above. The left-left and right-right lists were introduced after 45 sessions.

During the initial pretraining phase, when only the left-right and right-left lists were presented, and for 21 sessions after the left-left and right-right lists were introduced, the food hopper was always operated for 2.0 sec. The probability that the food hopper would be operated for only 0.25 sec was changed from 0.0 to 0.1 on the twenty-second session after the left-left and right-right lists were introduced and was then increased to 0.6 over the following 10 sessions.

RESULTS AND DISCUSSION

The results of Experiment 1 are summarized in Figure 1, which shows the probability of a correct side-key response in the test phase as a function of the serial position of the tested item. The probability of a correct response equals the frequency of trials on which a subject's choice was reinforced divided by the total number of trials. The probability of a correct response was based solely on choice responses. That is, results from correction trials were not included in the computation. Also, results before the second reinforcement were not included in an effort to avoid warm-up effects. The points in Figure 1 are averages over the last five days of each condition.

Figure 1 shows strong "recency" effects: the probability of a correct response was greater for the second, more recent, item. But the probability of a correct response when even the first item was tested was still very much greater than chance (0.5) after a 4-sec retention interval. Thus, the results indicate that a pigeon can to some extent remember for several sec-

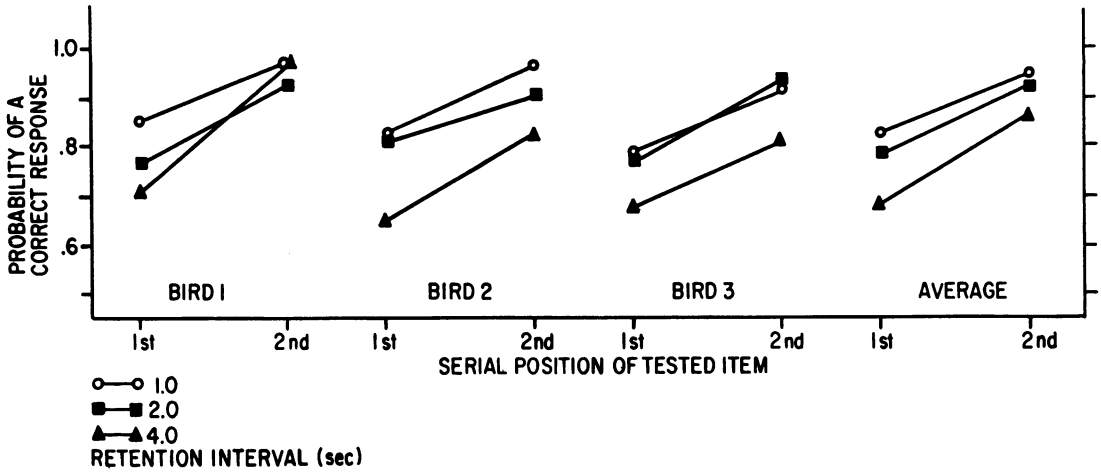


Fig. 1. The probability of a correct side-key response as a function of the retention interval and the serial position of the tested item in Experiment I.

onds the side-key responses most recently associated with two stimuli.

EXPERIMENT II

The purpose of Experiment II was to generalize the method developed in Experiment I to lists having three instead of two items.

METHOD

Subjects and Apparatus

The subjects and apparatus were the same as in Experiment I.

Procedure

The procedure was identical to that of Experiment I except that here, completion of the second item in the study phase began another 0.1-sec ISI instead of the retention interval. Upon completion of this ISI, a third stimulus, a white light, was presented on a randomly selected side key. A response to this side key terminated this item in the study phase and began a retention interval, which was varied across Conditions 4 to 7 as shown in Table 1. Note that in Experiment II there were eight possible lists in the study phase, rather than four as in Experiment I.

When the retention interval timed out, a red, blue, or white stimulus, all equally probable, appeared on the center key. The first peck on the center key turned it off and

turned the side keys on with the same color as had been on the center key. The subject now was required to emit the response element of the indicated item in the study phase: red, blue, or white indicated first, second, or third items, respectively. Thus, red and blue retained their meanings from Experiment I.

No additional pretraining was given between the end of Experiment I (Condition 3) and the beginning of Experiment II (Condition 4). However, the transition to Experiment II was facilitated by a very short retention interval of 0.5 sec in Condition 4.

RESULTS AND DISCUSSION

Figure 2 corresponds to Figure 1: it shows the probability of a correct side-key response in the test phase as a function of the serial position of the tested item in the list presented in the study phase. Figure 2 omits the first two trials and presents averages over the last five days of each condition.

Figure 2 shows that the pigeon's short-term memory for stimulus-response associations was sufficient to enable above-chance performance even with 4-sec retention intervals. Shorter retention intervals generally produced more accurate responding for items in all three serial positions. A recency effect similar to that in Experiment I was obtained: more recent items were remembered better than earlier ones. No "primacy effect" was observed: there was no indication that the first item in a list was remembered better than was the middle item.

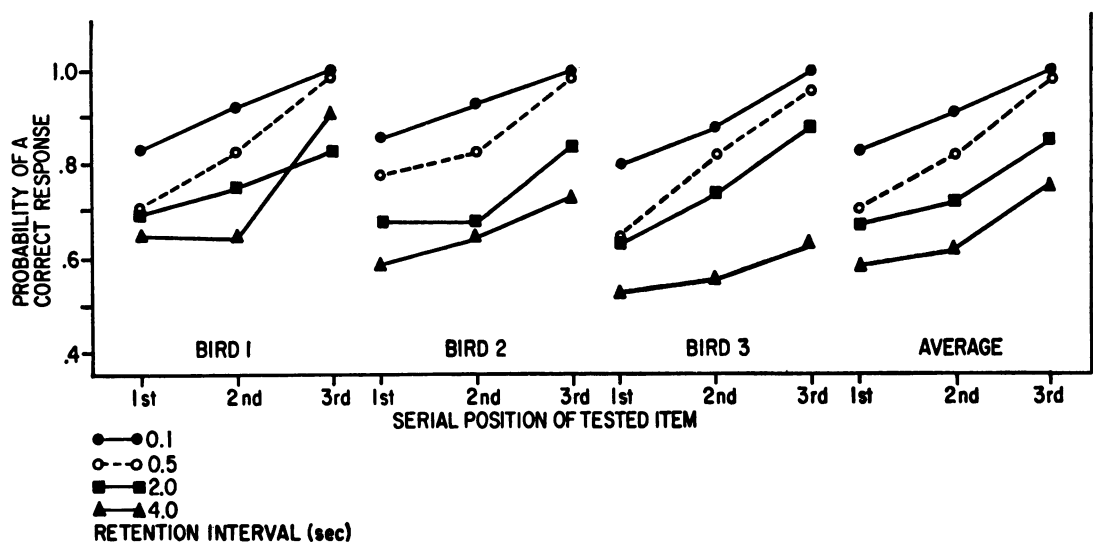


Fig. 2. The probability of a correct side-key response as a function of the retention interval and the serial position of the tested item in Experiment II.

GENERAL DISCUSSION

The present experiment successfully demonstrated the use of a method to study short-term memory for stimulus-response associations. The pigeon can encode successive stimulus-response associations in memory so that it can subsequently retrieve and emit the response element when given the stimulus element. The mechanism by means of which a pigeon does this remains for further research to determine.

It is worthwhile at this early stage of development of the present method to identify those parameters that can in general be expected to affect short-term memory for stimulus-response associations, but which here were held constant. The nature of stimuli presented during the retention interval, and the nature of the activity in which a subject engages during the retention interval, can be expected to affect performance through various levels of retroactive interference (Moffitt, 1972; Zentall, 1973). The number of items in the study phase list presumably also affects performance, at least partly through differences in the resulting sequential complexity of the lists. The intertrial interval and the ISI may also affect behavior. The exploration of the effects of these and similar variables would provide a more complete picture of the conditions under which a pigeon can remember the responses most recently associated with different stimuli.

The present results and other recent short-term memory data (Moffitt, 1972; Roberts, 1972; Zentall, 1973) may have far-reaching implications for the understanding of free-operant behavior. Data of this type raise the possibility that memory for recent events, for both stimuli and responses, constitutes part of the functional stimulus complex when a reinforcer is delivered. Thus, the delivery of a reinforcer may affect a host of stimulus-response associations apart from those involving the response temporally contiguous with reinforcement. Indeed, such brief reinforced responses as key pecks and lever presses may constitute only a small fraction of the pattern of response topographies affected by reinforcement. Such possibilities emphasize that nominally reinforced and functionally reinforced response classes may not be the same: reinforcement might establish and maintain behavioral patterns several seconds in duration. This possibility is consistent with conclusions derived from paradigms altogether different from short-term memory procedures. Other procedures have led to the conclusion that behavioral patterns may be established as functional units, *i.e.*, operants, even though only a small fraction of the behavior in these patterns is contiguous with reinforcement (Shimp, 1974; Hawkes and Shimp, *in press*). These functional response units, such as inter-response times, may be examples of "chunks" of organized behavior that function in

memory as integrated units (Tulving and Donaldson, 1972).

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